90-04512/

CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES
MINES BRANCH
OTTAWA

PHYSICAL METALLURGY DIVISION
INTERNAL REPORT PM-M-70-21

ALUMINUM-SILICON POWDER METALLURGY ALLOYS

by

H. M. Skelly and C. F. Dixon
Nuclear and Powder Metallurgy Section

September 4, 1970

PHYSICAL METALLURGY DIVISION
INTERNAL REPORT PM-M-70-21

ALUMINUM-SILICON POWDER METALLURGY ALLOYS

by
H. M. Skelly* and C. F. Dixon**

- - - - - - - - - - -

ABSTRACT

Hypereutectic aluminum-silicon powder metallurgy alloys containing up to 45% Si, in which the primary silicon phase was finely divided, were produced without the addition of nucleation catalysts. These alloys were consolidated by hot pressing.

Additions of copper and magnesium to an Al-35% Si powder metallurgy alloy had no effect on the finely divided primary silicon. However, these additions increased the hardness of hot-pressed and heat-treated specimens and also improved the tensile strength of the latter; wear resistance was improved, and the coefficient of thermal expansion was increased.

---

*Research Scientist and **Engineer, Nuclear and Powder Metallurgy Section, Physical Metallurgy Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.
Crown Copyright Reserved.

INTRODUCTION

Previous work in these laboratories[1] has shown that refined hypereutectic aluminum-silicon alloys containing up to 45% Si, can be produced by powder metallurgy techniques. Pre-alloyed powders, produced by atomizing molten alloys to which phosphorus and magnesium were added as nucleating catalysts were consolidated by cold pressing, followed by hot pressing and then extruding.

This investigation examines the possibility of producing hypereutectic aluminum-silicon powder metallurgy alloys with a fine dispersion of primary silicon without addition of nucleating catalysts. Also, the feasibility of consolidating the resulting powders by hot pressing alone is investigated, and the effect of alloying additions of copper and magnesium on the properties of the Al-35% Si composition is determined.

EXPERIMENTAL PROCEDURE

Preparation of Alloy Powders

Materials used to prepare the experimental pre-alloyed powders are listed in Table 1, and the compositions of the powders are listed in Table 2. Melting and alloying were carried out by conventional methods, then the melts were transferred to an apparatus in which jets of compressed air atomized a stream of molten metal into powder that was quenched in water. The powder was dried and screened through a 100-mesh sieve; the plus 100-mesh fraction was discarded.

Compacting and Hot Pressing

The alloy powders were cold-pressed, isostatically, at 10,000 psi for 5 min. All cold-pressed billets were heated in the hot die at temperature for 15 min, then a load of 38,000 psi was applied for 5 min. Al-25% Si,

Al-35% Si, and Al-45% Si alloys were hot-pressed at 550°C; the Al-35% Si alloy was also hot-pressed at the eutectic temperature, 577°C. Al-35% Si-Cu alloys (eutectic temperature 540°C) were hot-pressed at 510°C and 550°C, and Al-35% Si-Mg alloys (eutectic temperature 551°C) at 530°C and 560°C.

Heat Treating

For the purpose of investigating the effect of heat treatment on mechanical properties, specimens of Al-35% Si and Al-35% Si-Cu alloys were solution heat-treated at 520°C for 6 hr then quenched into boiling water, followed by ageing at 200°C for times up to 5 hr. The Al-35% Si-Mg alloys were solution heat-treated at 535°C for 6 hr, quenched into boiling water, then aged at 160°C for 4 hr.

Examination and Testing

Microexamination was carried out on the minus 100-mesh powders, on hot-pressed compacts, and on hot-pressed and heat-treated compacts.

Vickers hardness numbers (VHN) were determined for alloys in hot-pressed and heat-treated conditions.

Room temperature tensile tests were conducted on an Instron machine on all hot-pressed alloys and on Al-35% Si-Cu and Al-35% Si-Mg alloys after heat treating.

The coefficient of thermal expansion between 20°C and 300°C was determined for Al-35% Si, Al-35% Si-Cu and Al-35% Si-Mg alloys. Also, the wear resistance of these alloys was assessed by determining the loss of weight of a 1/8-in.-diameter by 1/2-in. long pin of the material after the end of the pin had been in dry contact with a rotating cast-iron disc. A pressure of 1000 psi was applied to the pin and the disc was rotated to give a speed of 200 in./min for 1 hr at the point of contact.

Samples for chemical analysis were taken from the minus 100-mesh powder.

RESULTS AND DISCUSSION

Alloy Compositions

Chemical analysis results are listed in Table 2. There was some loss of silicon in the Al-25% Si (24% Si), Al-35% Si (34% Si), and Al-45% Si (42.5% Si) alloys; and in the Al-35% Si-2% Mg alloy the magnesium content was low (1.4%). The 0.2% Fe in the powders was from the aluminum-silicon hardener. Al-25% Si and Al-45% Si alloys were made using pure silicon.

Silicon Refinement

The atomized powders contained a fine dispersion of primary silicon. Figure 1 is a photomicrograph showing the microstructure of the Al-35% Si powder and is typical of all the aluminum-silicon powders; the primary silicon phase shows as dark grey particles within the powder grains. The size of the primary silicon was not affected by the addition of copper and magnesium to the Al-35% Si alloy.

Figure 2 shows the structure of the hot-pressed Al-35% Si-2% Mg alloy, and is typical of all the hot-pressed alloys. The powder particles have bonded, there is little porosity, and there is no evidence of growth of the silicon particles during hot pressing. Also, no difference was observed in the primary silicon phase in specimens hot-pressed above and below the eutectic temperatures.

In addition to refinement of the primary silicon, it was observed that the eutectic phase was also extremely well refined. The eutectic is not discernible in Figures 1 and 2 because it was not resolved at the magnification used (X150).

Properties of Compacts

The effect of hot-pressing temperature and heat treatment on the hardness of the Al-35% Si, Al-35% Si-Cu and Al-35% Si-Mg alloys is shown in Tables 3 and 4. The hardness of the Al-35% Si alloy was not significantly influenced by the hot-pressing temperature or by the heat treatment. Additions of 1% Cu increased the hardness of hot-pressed specimens, but heat treatment had little effect on this alloy. Additions of 2.5% Cu further increased the hardness of hot-pressed specimens and, after solution heat treating and then

ageing for 1 hr, specimens that were hot-pressed at 550°C increased in hardness from 138 to 178 VHN.

The Al-Si-Mg alloys were given the heat treatment recommended for a commercial aluminum alloy containing silicon and magnesium. Results in Table 4 show that the heat-treated specimens were harder than those that were hot-pressed only.

Aged specimens of the Al-35% Si-Cu and Al-35% Si-Mg alloys hot-pressed above their eutectic temperature were harder than those hot-pressed below the eutectic temperature.

Tensile properties of the hot-pressed alloys are listed in Table 5; included are values for Al-Si-Cu and Al-Si-Mg alloys heat-treated to give the hardnesses underlined in Tables 3 and 4. Also included, for reference, are values for a cast aluminum piston alloy containing 22-25% Si, 0.8-1.0% Ni, 0.4-0.6 % Cr, 0.8-1.2% Cu,and 0.7-1.2% Mg[2]. From these results, it is evident that the tensile strength of hot-pressed alloys increased with silicon content. The tensile strength for the Al-45% Si Alloy was lower than that of a previously examined Al-45% Si hot-pressed powder-metallurgy alloy[1]. However, the latter contained 0.35% Cu and 1.05% Mg and was subjected to a considerably higher pressure during an unsuccessful attempt to extrude it.

Of the specimens tested, those with the highest tensile strengths were: Al-35% Si-2.5% Cu hot-pressed at 550°C and aged for 1 hr (30.2 kpsi), Al-35% Si-1% Mg hot-pressed at 530°C and aged for 4 hr (32.7 kpsi) and Al-35% Si-2% Mg hot-pressed at 530°C and aged for 4 hr (29.4 kpsi). These results showed that additions of copper and magnesium to the Al-35% Si alloy increased the tensile strength after ageing by 20% and 30% respectively. All the powder metallurgy alloys exhibited low ductility, which is usual for hypereutectic aluminum-silicon alloys.

Results in Table 5 also show an improvement in tensile strength for some of the material hot-pressed above the eutectic as compared with material hot-pressed below the eutectic; however, the problems of hot pressing in the presence of a liquid phase would possibly offset the improvement in strength.

The coefficients of thermal expansion are listed in Table 6 which also includes the published value for the cast piston alloy. These results show that the coefficient of thermal expansion for the Al-35% Si alloy was increased by the addition of copper and magnesium.

Results in Table 7 shows that the additions of copper and magnesium improved the wear resistance of the Al-35% Si powder metallurgy alloy.

CONCLUSIONS

1. Atomizing aluminum-silicon alloys containing up to 45% Si, without addition of refining elements, produces a fine dispersion of the primary silicon phase.
2. Atomized powders of hypereutectic aluminum-silicon alloys can be consolidated by hot pressing.
3. Addition of copper and magnesium to an Al-35% Si powder metallurgy alloy increases the hardness of hot-pressed and heat-treated specimens.
4. Addition of 2.5% Cu, 1% Mg or 2% Mg to the Al-35% Si powder metallurgy alloy increases the tensile strength after ageing.
5. The coefficient of thermal expansion of the Al-35% Si powder metallurgy alloy is slightly increased by the addition of copper and magnesium.
6. Wear resistance of the Al-35% Si powder metallurgy alloy is increased by the addition of copper and magnesium.

REFERENCE

1. C. F. Dixon and H. M. Skelly. "Hypereutectic Aluminum-Silicon Alloys Produced by Powder Metallurgy Techniques". Int. J. Powder Metallurgy 1 (4), 28-36 (October 1965).
2. H. Kessler. "Aluminum Piston Alloys in Germany". Light Metals 85-88 (March 1958).

TABLE 1

Alloy Materials

Material	Purity	Source
Aluminum	99.99%	Aluminum Co. of Canada Ltd.
Silicon	99.1%	Union Carbide of Canada Ltd.
Al-50% Si Hardner	48.5% Si, 0.26% Fe	Kawecki Chemical Co.
Magnesium	99.9%	Dominion Magnesium Ltd.
Copper	O.F.H.C.	American Metals Climax Inc.

TABLE 2

Alloy Composition

Nominal Composition	Chemical Composition (%)			
	Si	Cu	Mg	Fe*
Al-25% Si	24.0	-	-	-
Al-35% Si	34.0	-	-	0.2
Al-35% Si-1% Cu	35.3	1.0	-	0.2
Al-35% Si-2.5% Cu	34.6	2.5	-	0.2
Al-35% Si-1% Mg	35.3	-	0.9	0.2
Al-35% Si-2% Mg	36.0	-	1.4	0.2
Al-45% Si	42.5	-	-	-

*Powders made with Al-50% Si hardener contained 0.2% iron.

TABLE 3

Hardness of Al-35% Si and Al-35% Si-Cu Alloys

Alloy	Hot Press Temp °C	VHN (5 Kg)						
		Hot-Pressed	Sol. H. T.* 520° C 6 hr	Aged 200°C				
				1 hr	2 hr	3 hr	4 hr	5 hr
Al-35% Si	550	85	94	93	93	95	86	88
Al-35% Si	577	78	92	-	88	90	84	84
Al-35% Si-1% Cu	510	128	123	124	120	126	115	117
Al-35% Si-1% Cu	550	123	125	124	131	131	124	119
Al-35% Si-2.5% Cu	510	132	157	143	147	151	141	135
Al-35% Si-2.5% Cu	550	138	152	178	176	169	165	161

*Solution Heat Treated

TABLE 4

Hardness of Al-35% Si-Mg Alloys

Alloy	Hot Press Temp °C	VHN (5 Kg)		
		Hot Pressed	Sol. H. T.* 535°C 6 hr	Aged 160°C 4 hr
Al-35% Si-1% Mg	530	95	130	156
Al-35% Si-1% Mg	560	94	142	164
Al-35% Si-2% Mg	530	100	138	160
Al-35% Si-2% Mg	560	115	150	183

*Solution Heat Treated

TABLE 5

Mechanical Properties

Alloy (Nominal Composition)	Hot Press Temp °C	Condition	UTS (kpsi)	0.2% YS (kpsi)	% El $\sqrt{4\text{area}}$	VHN (Kg)
Al-25% Si	550	Hot Pressed	22.5	16.5	3	56
Al-45% Si	550	Hot Pressed	27.5	-	2	114
Al-35% Si	550	Hot Pressed	24.9	23.4	3	85
Al-35% Si	577	Hot Pressed	23.6	22.7	2	78
Al-35% Si-1% Cu	510	Hot Pressed	22.5	-	2.5	128
Al-35% Si-1% Cu	550	Hot Pressed	26.7	-	2.0	123
Al-35% Si-1% Cu	510	Sol. H.T.**	22.6	-	1	123
Al-35% Si-1% Cu	550	Aged 2 hr	24.8	-	2	131
Al-35% Si-2.5% Cu	510	Hot Pressed	21.4	-	1.5	132
Al-35% Si-2.5% Cu	550	Hot Pressed	24 5	-	2 5	138
Al-35% Si-2.5% Cu	510	Sol H T.	25.2	-	1	157
Al-35% Si-2.5% Cu	550	Aged 1 hr	30.2	-	1	178
Al-35% Si-1% Mg	530	Hot Pressed	25.3	25.3	2.0	95
Al-35% Si-1% Mg	560	Hot Pressed	26.3	25.9	2.0	94
Al-35% Si-1% Mg	530	Aged 4 hr	32.7	-	1.5	156
Al-35% Si-2% Mg	530	Hot Pressed	26.8	25.8	1.5	100
Al-35% Si-2% Mg	560	Hot Pressed	22.2	-	2.0	115
Al-35% Si-2% Mg	530	Aged 4 hr	29.4	-	2.0	160
Al-22 to 25% Si*		Heat treated	26-31		0.1-0.3	98-135

*Cast Piston Alloy[2]
**Solution Heat Treated.

TABLE 6

Thermal Expansion Coefficients

(Temperature Range 20-300°C)

Alloy	Coefficient (in./in./°C x 10^6)
Al-35% Si	15.41
Al-35% Si-1% Cu	16.23
Al-35% Si-2.5% Cu	16.12
Al-35% Si-1% Mg	16.40
Al-35% Si-2% Mg	16.43
Al-22 to 25% Si*	16-17

*Cast Piston Alloy[2], Temperature Range 20-200°C

TABLE 7

Wear Test Results

Alloy	Weight Loss after 1 hr ($g \times 10^{4}$)
Al-35% Si	142
Al-35% Si-1% Cu	102
Al-35% Si-2.5% Cu	93
Al-35% Si-1% Mg	104
Al-35% Si-2% Mg	116

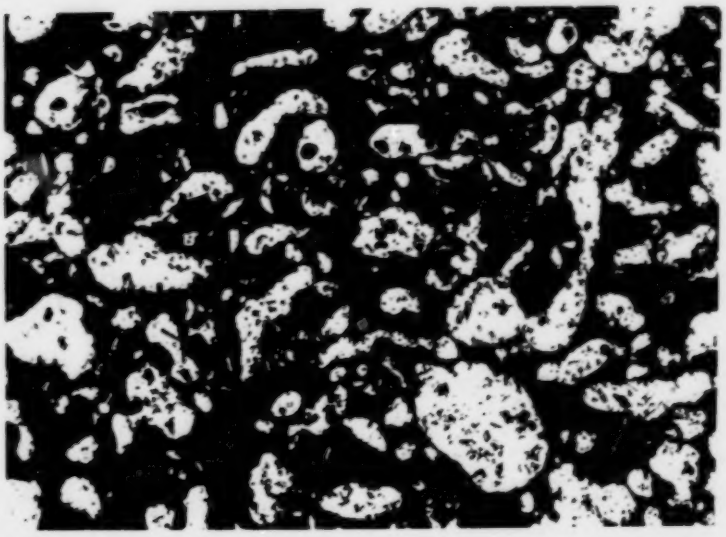

Figure 1. Al-35% Si powder. Minus 100-mesh. X150.

Figure 2. Al-35% Si-2% Mg. Hot-pressed 530°C. X150.